SOCIAL INFLUENCE IN PIGEONS (COLUMBA LIVIA): THE ROLE OF DIFFERENTIAL REINFORCEMENT

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Socially-influenced learning was studied in observer pigeons that observed a demonstrator in an adjacent chamber performing a target response comprising standing on a box and pecking a key 10 times. In Experiment 1 there was no evidence for social learning in the absence of reinforcement of the observer's behavior. When the target response was already established in the observer's repertoire, but was not differentially reinforced in relation to the demonstrator's behavior, rates of extinction were not influenced by the demonstrator's behavior (Experiment 2). Reinforcement of the observer's target response in the presence of the modeled target response, and not in its absence, resulted in control of the observer's responding by the behavior of the demonstrator (Experiments 3 and 4). This control was extended in Experiment 5 to deferred responses that occurred following a delay since the demonstrator's target responses. The acquisition of social influence depended on differential reinforcement of the observer's target response, with the demonstrator's target behavior serving as the explicit discriminative stimulus.

Key words: social influence, matched-dependent learning, imitation, discriminative stimulus control, differential reinforcement, pigeon

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Social influence of an observer's behavior by the behavior of a conspecific demonstrator may involve several different mechanisms (Howard & Keenan, 1993; Thorpe, 1963; Zentall, 1996). In the present paper we suggest that some types of socially-influenced learning could depend on the observer's prior reinforcement history. The issue is of interest because social learning such as imitation, where an action is learned by seeing it done (Galef, 1988), is regarded as an alternative to learning through reinforcement. Here we report the occurrence of behavior that fulfills all but one of the criteria for imitative behavior. The exception is that it was necessary to establish the behavior through differential reinforcement, a procedure which precludes it from being referred to as *true imitation* (Zentall, 1996). The behavior therefore is an instance of *matched-dependent learning* (Miller & Dollard, 1941). The present experiments, and the results from prior studies of imitation where behavior was explicitly reinforced, suggest that social learning follows the principles of discriminative stimulus control and question whether imitation can be distinguished from matched-dependent learning.

Hake, Donaldson, and Hyten (1983) dem-

onstrated matched-dependent learning in rats. Pressing a high or low response key by a demonstrator gained stimulus control on a trial by trial basis over similarly positioned key pressing by an observer in an adjacent chamber. Differential reinforcement was arranged in that pressing the appropriate key by the observer was reinforced and pressing the wrong key was not. In the study by Hake et al., stimulus enhancement or local enhancement was possible. That is, the demonstrator's activity at a particular location (or stimulus) may draw the attention of the observer to that location or stimulus (Zentall, 1996). In Hake et al.'s study, the operanda differed in position (or in color in a later study by Fushimi [1990]), and this feature, not the topography of the demonstrator's behavior, may have provided the source of control. In a later study by Heyes and Dawson (1990), olfactory cues provided the source of local enhancement. They trained demonstrator rats to push a joystick either to the right or to the left. Observer rats watched the demonstrator from an adjacent location and were later allowed access to the joystick in the same location as the demonstrator and in the demonstrator's chamber. The observers pushed the operandum in the same direction as the demonstrator significantly more often than in the opposite direction. In a later study, this occurred even when the rod was moved to a new location (Heyes, Dawson, & Nokes,

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1992). The possibility that odor cues on the rod attracted the observers to the same side of the rod as the demonstrator was confirmed by Mitchell, Heyes, Gardner, and Dawson (1999). In the studies by Heyes and colleagues, reinforcement history may have played a role in addition to local enhancement in that the observer's lever presses were reinforced. For example, the direction of the first response may have been determined by odor cues, and the subsequent responses would be strengthened by the reinforcement contingency. Although the results from such "two-action" studies have been treated as evidence for imitation (Heyes, 1998), the role of differential reinforcement cannot be neglected.

In a demonstration of matched-dependent learning, Millard (1979) reported stimulus control of pecking in pigeons by the responding of a conspecific. One schedule arranged reinforcement of high rates of responding by the demonstrator while another schedule arranged reinforcement of low rates of responding. In an adjacent chamber, the observers had access to the same schedules of reinforcement as the demonstrator and could view the demonstrator's behavior. When the demonstrator pecked at a high rate in one condition and at a low rate in another condition, the observer also pecked at high and low rates respectively, in such a way that individual pecks by the observer were more likely to follow pecks made by the demonstrator than by chance. By using separate chambers for observers and demonstrators, local enhancement or stimulus enhancement was unlikely. Differential reinforcement of the observer's behavior may nonetheless have been important in establishing stimulus control by the conspecific's behavior.

In the present experiments, which used pigeons as subjects, using separate operanda and chambers for observer and demonstrator eliminated local enhancement and stimulus enhancement. This method was first used by Warden and Jackson (1935). Social facilitation, where the mere presence of a conspecific may increase the probability of a behavior, is another potential source of social influence, and was eliminated or minimized in the present experiments by deferring the opportunity for the observers to respond to a time that followed the occurrence of the demonstrator's behavior, and by including control conditions in which only the demonstrator was fed. In "target" conditions or components, the demonstrator's behavior of standing on a box and pecking a key 10 times was reinforced. In control conditions, the demonstrator's behavior was reinforced at the same rate as in the target conditions, so long as the target behavior did not occur (differential reinforcement of other behavior). This eliminated the possibility that the rate of reinforcer delivery in the demonstrator's chamber could serve as a discriminative stimulus for the observer's behavior. The control condition also precluded the possibility of social facilitation because the demonstrator was present and eating at the same rate in both target and control conditions.

In Experiment 1 of the present study, the observer's behavior was never explicitly reinforced, and social learning did not occur. In Experiment 2, the observer's target response was established through reinforcement but was not differentially reinforced in relation to the demonstrator's behavior. When reinforcement was withheld, there was no effect of the demonstrator's behavior on the rate of extinction of the observer's target response. In Experiments 3 and 4, the observer's behavior was brought under discriminative control by the same behavior of the demonstrator, and in Experiment 5 this control was deferred by deferring the opportunity for the observer to emit the same behavior as the demonstrator to a later time. Social learning was demonstrated in Experiments 3 through 5, but only once discriminative control had been established through differential reinforcement.

EXPERIMENT 1

The aim of Experiment 1 was to determine whether homing pigeons would copy the novel behavior of a conspecific when they were proficient in the individual components of the behavior. The majority of novel response topographies emitted by adult animals occur when smaller nonnovel behavioral units are combined in new ways (Lubinski & Thompson, 1987). For example, in the case of a tit breaking open a milk bottle top for the first time, pecking is already established, pecking holes in other objects such as mushrooms has been learned, and pecking at bright objects

is highly likely. In the present experiments the target response involved two components: standing on a box and then pecking a key 10 times. The observers in Experiment 1 were trained to keypeck in the absence of the box, and, separately, all performed box standing without explicit training. That is, the two responses were already in the observers' repertoire before the opportunity was provided to perform the target response (box stand then key peck) following observation of the demonstrator performing the target response. The observer's opportunity to perform the target response was deferred in that it followed the time available for the demonstrator's response. At no time was reinforcement arranged for the observer's completion of the target response.

METHOD

Subjects

Six adult homing pigeons were used. Pigeons N2, N3, N4 and N5 acted as observers. Two were naive (Pigeons N2 and N3) and two had a prior history in delayed matching to sample procedures. Two male pigeons, one with prior experience in delayed matching to sample and the other naive (Pigeons N1 and ND) were selected on the basis of their physical similarity to act as demonstrators. During preexperimental observation the naive pigeon (ND) showed no tendency to peck the response key. Training and experimental sessions were conducted each morning. The pigeons were housed individually in a colony room kept between 19 and 21° C. The room had natural lighting from a window and was also illuminated on an approximate 16:8 hr light/dark cycle from overhead fluorescent lighting. Each pigeon was maintained at 85% ± 10 g of its free feeding weight by supplementary feeding. In their home cages, they had free access to water and supplementary feeding with mixed grain occurred at the end of the afternoon.

Apparatus

The pigeons were trained and tested in a custom-built experimental chamber (Figure 1). The walls and floor of the chamber were constructed from plywood painted white, and the ceiling was clear plastic. A clear plastic partition divided the chamber into two com-
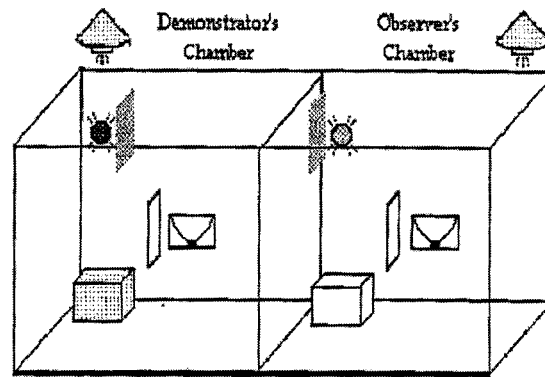

Fig. 1. Illustration of the apparatus. The demonstrator's chamber on the left and the observer's chamber on the right could be illuminated by houselights mounted above the chambers. Response keys at the left of the rear wall and inset were shielded from the view of the pigeon in the other chamber by small barriers. In each chamber, a barrier to the left of each centrally located hopper prevented the pigeon from feeding while it was on the box.

partments of equal size. The left compartment was the demonstrator's chamber and the right compartment was the observer's chamber. The interior of each chamber was 35 cm wide, 47 cm deep and 42 cm high. Each chamber could be illuminated by a 230 V, 8 W houselight positioned above the chamber and next to the outside wall. A magazine tray accessed through a 6.5 cm by 5 cm opening was centrally positioned in each chamber behind the front panel and 7.5 cm above the grid floor. There were two response keys 3 cm diameter in each chamber. The right key in the demonstrator's chamber was always covered (taped over). During all experimental sessions, the right key in the observer's chamber was covered and the left key was uncovered, but during preliminary training the right key in the observer's chamber was uncovered and the left key was covered. Each response key was mounted 28.5 cm from the floor and 8 cm left or right of center. Each key could be operated by a force of at least 0.1 N. Light-emitting diode lamps behind each response key could transilluminate the key with colored light (red, green, or yellow). The response keys in each chamber were positioned just out of reach of the pigeons. Access to them was facilitated by positioning a box (10 cm wide, 7.5 cm deep, and 5.7 cm high) under a key or by raising the floor of the chamber, depending on whether the pi-

geons were in training or experimental conditions.

The left response key in the demonstrator's chamber was occluded from the observer's view from the observer's chamber by the 1.2-cm indentation of the keylights behind the front panel and by a small opaque vertical barrier. The barrier was 2 cm wide and 6.5 cm high and was mounted to the immediate right of the key. A similar barrier was mounted to the immediate left of the left response key in the observer's chamber.

The uncovered response key in the demonstrator's chamber was just out of reach of Pigeons N1 and ND. By standing on the small box placed under the key, however, these pigeons could reach and peck the response key. A weight of 118 g (easily achieved by any of the pigeons) was sufficient to close microswitches inside the box. The box placed under the left key in the demonstrator's chamber was painted brown and the box in the observer's chamber was painted white to decrease the likelihood of stimulus enhancement. In each chamber, a clear plastic barrier (8 cm wide and 13 cm high) was positioned perpendicular to the panel between the magazine tray and the box, which prevented a pigeon on the box from feeding from the magazine tray without first getting off the box. This barrier did not obstruct the view of the demonstrator from the observer's chamber.

Closure of switches in the boxes and response keys and the operation of key lights and house lights were recorded and controlled by a BBC Master microcomputer via an interface using the enhanced BASIC® programming language SPIDER (Paul Fray Ltd). The chamber, computer, and interface were located in a small ventilated room.

Procedure

Preliminary training for the observers. During preliminary training, the floor of the observer's chamber was raised 6 cm. The left key was covered and the right key was uncovered. With the floor raised by 6 cm, no box in the chamber, and the key lit red, the observers were trained to peck the response key. Initially, each observer was magazine trained until it fed from the tray 10 times in the observer's chamber. Each pigeon was then trained to peck the right key in the observer's chamber using an autoshaping procedure in which

the key was lit red for 8 s, followed by 4-s access to the magazine tray, and a 60-s intertrial interval. Each response was followed by food delivery and the session terminated after 10 such reinforcers. In subsequent sessions, the fixed-ratio (FR) requirement was incremented by one response per session up to FR 10, and each session ended after 10 reinforcers. In further sessions a blackout followed each reinforcer. Blackouts lasted for 60 s and any response during the blackout reset the blackout timer. Actual blackout durations varied between 60 s and 180 s.

Final sessions of preliminary training consisted of six components, each 120 s in duration. Prior to each component there was a 120-s blackout period in the observer's chamber during which only the demonstrator's chamber was lit. After the 120-s period elapsed, the lights and keylight in the demonstrator's chamber were turned off and the red keylight and the houselight in the observer's chamber were illuminated to signal the onset of the observer's 120-s component. The houselight in the demonstrator's chamber was turned off during the observer's 120-s component. In the presence of the red keylight in the observer's chamber and the observer's houselight, every tenth key peck was reinforced with 3-s access to grain during which time the keylight was temporarily offset. Thus, each session began with a 120-s blackout period followed immediately by a 120-s component. This was immediately followed by another blackout period and another 120-s component, and so on, for a total of six components. At this point the session ended in blackout. The observers were trained for between 20 and 30 sessions until the following criteria were met: For each of three consecutive sessions, (a) mean latency across components to complete the first FR 10 was less than 15 s, (b) total FR 10 units in a session did not vary by more than three over three consecutive sessions, and (c) fewer than four single key pecks occurred in blackout periods. Once the criteria were met, the last session was conducted in the presence of a naive pigeon in the demonstrator's chamber. In the last session of preliminary training, with the keys covered, the floor lowered, and the box placed under the position of the left key which remained covered, each pigeon spontaneously stepped up on the box.

Preliminary training for the demonstrator. Training sessions were organized in the same way as those for the observers, except that only the left key was used. The right key in the demonstrator's chamber was always covered. Each target response (standing on the box and pecking the left key 10 times) by Pigeon N1 was reinforced when the left key was lit green (continuous reinforcement, CRF). For Pigeon ND (feeding-only control), when the left key was lit red, food delivery was contingent on the pigeon *not* emitting any aspects of the target response for periods of time chosen to approximate the rate of reinforcers obtained by Pigeon N1 (differential reinforcement of other behavior, DRO). The different keylight colors for demonstrators were arbitrary at this stage but corresponded to the discriminative stimuli alternated within session in the following experiments. Training continued until Pigeon N1 was performing the target response at a consistent rate, responses did not occur during blackouts, and Pigeon ND was consistently feeding without ever emitting the target response.

Experimental sessions. During experimental sessions, the observer's opportunity to perform was deferred in that the observer's 120-s component immediately followed a period of the demonstrator responding (N1) or feeding (ND). For this reason, blackout periods were included in training and experimental sessions in which responses were not reinforced and both the keylight and the house light in the observer's or demonstrator's chamber were not illuminated.

Each observer participated in two conditions: a Target Condition and a Control Condition. To take account of order effects, the order of these conditions for Pigeons N2 and N4 was reversed for Pigeons N3 and N5. Each condition comprised 10 sessions. The floor in the observer's box was lowered, the right key covered, and the left key uncovered. In the Target Condition, each session consisted of six components in which the observers were exposed to Pigeon N1 performing target responses, while in the Control Condition the observers were exposed to Pigeon ND being fed at periodic intervals. A component began with the onset of the demonstrator's keylight and houselights. After the demonstrator had received 10 reinforcers, the houselights and keylight in the demonstrator's chamber were

turned off and the houselights and yellow keylight on the left response key in the observer's chamber were illuminated. Houselight and keylight illumination in the observer's chamber lasted for 120 s and was followed by a dark intercomponent interval of about 15 s during which houselights above both chambers and all keylights were unlit. The observer's behavior was not reinforced at any time during any of the components.

RESULTS AND DISCUSSION

Demonstrator Pigeon N1 consistently emitted target responses across the 10 sessions of the target conditions at a rate averaging seven responses per minute (range 4 to 10 over a total of 40 sessions). Response rates were calculated in terms of the total time available to emit target responses; that is, component duration minus reinforcer duration. Demonstrator Pigeon ND did not emit any target responses during the control conditions.

Virtually no target responses were emitted by the four observers over the total of 20 sessions conducted with each pigeon. One or two target responses were emitted by Pigeons N2 and N3 in control conditions. Social learning, therefore, did not occur in Experiment 1 although the observers had learned the behavioral components of the target response. Mere exposure of observers to demonstrators performing the target response was insufficient here to occasion target responding in the observers.

EXPERIMENT 2

In Experiment 1, consistent with the criteria for demonstrating true imitation (Zentall, 1996), the possibility of social facilitation was precluded by using a deferred procedure in which the observer's opportunity to perform was delayed relative to the demonstrator's behavior. Additionally, the possibility of local enhancement was precluded by the use of separate chambers for demonstrator and observer. In contrast, in studies of matched-dependent learning, matched responses are reinforced (Millard, 1979). In such cases, reinforcement of the first response emitted may have a strong facilitative effect on future repetitions of that response. For example, Neuringer (1969) showed that only three reinforced responses were sufficient to sustain

superstitious responding over a long period. Thus, under conditions in which matched-dependent learning occurs, an initial slight tendency to perform the same response as the demonstrator will be amplified once that response has been reinforced. The problem of amplifying an initial response tendency can be avoided by explicitly establishing the target response through reinforcement and then extinguishing the behavior in the presence of the demonstrator performing a similar response. The expectation is that the presence of the demonstrator performing a similar task will retard the rate of extinction.

To our knowledge only one other study has taken this approach. Treichler, Graham, and Schweikert (1971) found that bar pressing by rats extinguished more slowly when in the presence of a bar-pressing conspecific (also in extinction), but they did not control for the possibility of social facilitation. There were three sets of conditions in the present Experiment 2. In the first set, the observers were trained, in the absence of any pigeon, to emit the target response (stand on the box and peck the response key 10 times) and then reinforcement was withheld (Extinction). Extinction of observers' responding took place after a period of the observer observing either the demonstrator performing the target response or the demonstrator being fed only. In the second set of conditions, the observers were retrained, but in the presence of the demonstrator, to examine whether the effect of extinction depended on whether the demonstrator was present during training. Extinction sessions in the first two sets of conditions were conducted using the deferred procedure (when the observer's opportunity to perform was delayed relative to the demonstrator). In the third set of conditions, the procedure for the first set was repeated, except that reinforcement of the observer's target responses was withheld in the presence of the demonstrator which continued to perform the target response.

Method

Subjects and Apparatus

Subjects and apparatus were as in Experiment 1. The box in the observer's chamber was placed under the left uncovered response key, the floor was lowered, and the right response key was covered.

Procedure

Initially the observers were trained for between three and seven sessions to perform target responses when the yellow keylight was illuminated. Keypecking under the fixed-ratio requirement of 10 responses had already been trained in Experiment 1, and, separately, the occurrence of unreinforced box standing had been established. With the box under the uncovered left key, the target response occurred spontaneously within the first few sessions of Experiment 2. Once it had occurred, each target response was followed by 3-s access to grain. The yellow keylight was turned off during food delivery. Because Pigeon N4 was slower to get off the box in time to reach the hopper, its reinforcer duration was 6 s. By experimenter observation, these reinforcer durations allowed each pigeon to eat for 2 s. The procedure for each session was as in Experiment 1, with six 120-s components preceded by blackouts. Training sessions were carried out in the absence of any other pigeon until performance achieved the criterion described in Experiment 1, but applied to the whole target response and for a single session.

Pigeons N2, N3, and N4 participated in the first set of two conditions. In the first four sessions of each condition (Sessions 1 through 4 and 8 through 11), each target response was reinforced with no conspecific in the adjoining chamber. In the next three sessions of each condition (Sessions 5 through 7 and 12 through 14), reinforcement was withheld (Extinction). For pigeons N3 and N4, Sessions 5 through 7 included components where each of the observer's 120-s components was preceded by the demonstrator performing 10 reinforced target responses, and Sessions 12 through 14 included components preceded by the demonstrator being fed according to the DRO schedule. For Pigeon N2, components for the first three extinction sessions were preceded by the demonstrator being fed (DRO) and components for the second three extinction sessions were preceded by the demonstrator performing reinforced target responses.

All four pigeons participated in the second set of two conditions. These were identical to
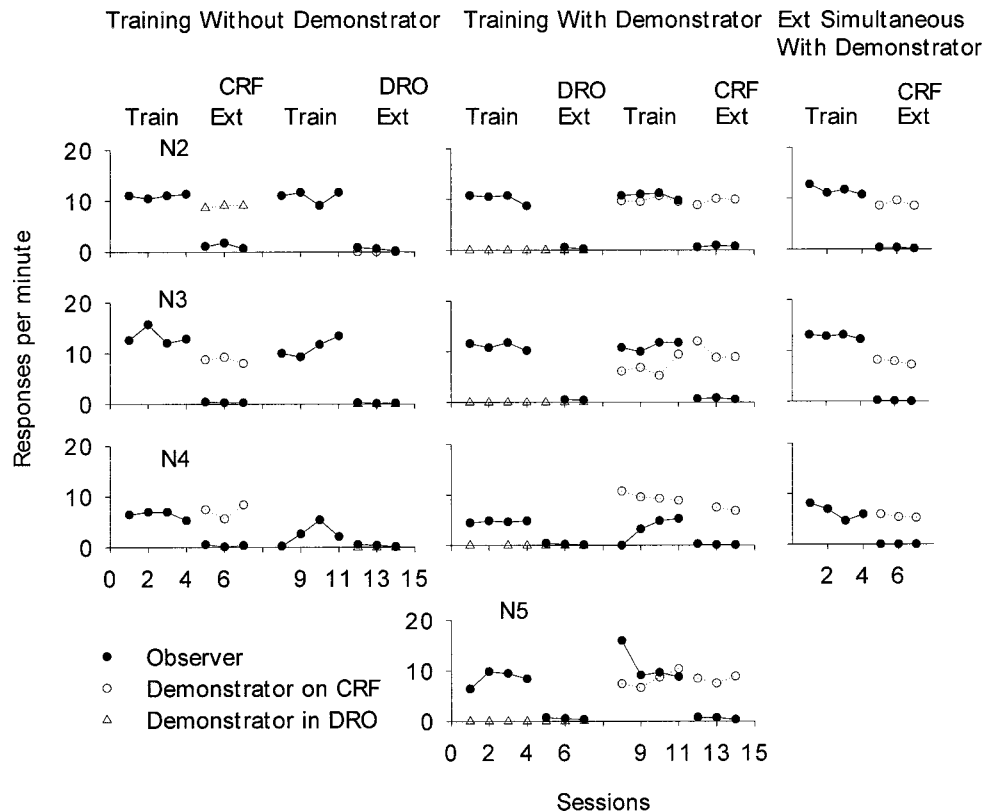
Fig. 2. Mean target responses (step on the box and peck 10 times) per minute for observers (filled circles) and demonstrators (unfilled symbols) in conditions of Experiment 2 when the observer was trained without or with the demonstrator present (left and center panels). Extinction sessions were conducted when the observer's behavior was deferred from occurrence of the demonstrator's responses, or was simultaneous with the demonstrator responding (right panel), and under conditions where the demonstrator responded (CRF) or was fed only (DRO).

the first set, except that in the first four training sessions the observers' target responses were reinforced in the presence of the demonstrator. The first four training sessions and the next three extinction sessions were all conducted with the demonstrator on the DRO schedule (feeding-only control). The next four training sessions and three extinction sessions were all conducted with the demonstrator performing reinforced target responses.

In the third set, the procedure for the first two training and extinction conditions was repeated (where there was no demonstrator present in training), except that the demonstrator's chamber was illuminated at the same time as the observer's during 120-s components of the extinction sessions and the demonstrator performed reinforced target responses simultaneously with the opportunity

for the observer to perform target responses (which did not produce reinforcers).

RESULTS AND DISCUSSION

Figure 2 shows that during the training sessions of the different conditions, the observers performed between 5 and 15 target responses per minute (across pigeons), and the rate of response across sessions was consistent within each pigeon. In conditions where demonstrators performed reinforced target responses, demonstrator response rates were consistent across sessions and at a similar level to the rates of response emitted by the observers. Demonstrators emitted no target responses when they were fed only, according to the DRO schedule. In all five conditions where extinction was arranged, the observers' rates of target responses were low and virtually zero in the last two extinction sessions

(Figure 2). Figure 2 shows that there were no differences in observers' response rates in Extinction when the demonstrator was responding (CRF) or fed only (DRO). There were also few target responses emitted in the first extinction session because the rate of extinction was very rapid. In particular, there were no differences between any of the conditions in the rates of extinction.

The low response rates in extinction may not have revealed a possible facilitation effect of having observed the demonstrator. Further analyses were therefore conducted of responses in components in the first extinction session, and of latencies to the first target response in each component across components of the first extinction session. These analyses showed no differences in the rate of extinction between any of the conditions. In the first extinction sessions, box-standing tended to persist in the absence of completion of the fixed-ratio requirement, especially for Pigeon N2. Persistence of the box-standing component did not differ, however, as a function of demonstrator condition. Whether the observer's component was preceded by the demonstrator's reinforced target responding, or was simultaneous with the demonstrator's reinforced target responding, made no difference to the rate of extinction compared to feed-only control conditions.

The findings of Experiment 2 were not consistent with those of Treichler, Graham, and Schweikert (1971). They reported that lever pressing by rats trained alone subsequently extinguished more slowly in the presence of a similarly behaving conspecific, whereas in the present study extinction occurred rapidly. Some differences between the studies, in addition to the subject differences, were the size of the response unit, the experimental histories of the observers, and delay of the observer's opportunity to respond. The result reported by Treichler et al. may therefore have reflected a social facilitation effect.

The result for the simultaneous condition is not consistent with the result reported by Epstein (1984, Experiment 1) who found that simultaneous imitation (pecking a ping-pong ball) occurred more readily than deferred imitation. One possible explanation for this difference was that the responses in Epstein's study had never been trained whereas the observers' experimental histories in the present

study may have led to rapid extinction when reinforcement was withheld. Epstein used a one-element (peck only) response and the current experiment used a two-element response of step-on-box-then-peck. The one-element response may have been more subject to social facilitation.

EXPERIMENT 3

In Experiments 1 and 2, there was no evidence of social influence of the observer's behavior. For social learning to occur, an observer presumably must attend to the stimulus properties of the demonstrator's behavior and respond similarly. Typically, a functional relation between a discriminative stimulus and behavior is established through differential reinforcement (Catania, 1988). Differential reinforcement may therefore play a role in the development of matched-dependent responding in the observer.

In Experiment 3, the role of differential reinforcement in the acquisition of social learning was examined. Within a session, the observer's target responses were continuously reinforced when the demonstrator was modeling the same response, and they were not reinforced (Extinction) when the demonstrator did not perform the target response but was being fed only (according to a DRO schedule). The reinforcement and extinction schedules for the observer were signaled only by the behavior of the demonstrator.

METHOD

Subjects and Apparatus

The subjects and apparatus were as in Experiment 1.

Procedure

In each session, opportunities for the observer to respond were simultaneous with the component in which the demonstrator responded, as in the last condition of Experiment 2.

Preliminary training for the observers. This experiment followed from Experiment 2 in which the observers had been trained in the target response of standing on the box and pecking the response key 10 times. In the presence of the response key lit yellow, the 10th peck was followed by 4-s access to grain

(7 s in the case of Pigeon N4). The observer's target response was topographically the same as the target response of the demonstrator although the operanda were in different locations and of different color to minimize the likelihood of local enhancement. The observer's keylight was turned off following competion of the target response and was reilluminated after reinforcer delivery (or after 4 s if the response was not reinforced) only if the observer was off the box. In each of four sessions, there were six 120-s components, as in Experiment 1. Blackout periods averaging 60 s (range 40 s to 80 s) separated components.

Preliminary training for the demonstrators (Pigeons N1 and ND). Sessions comprised three CRF and three DRO schedule components directly alternating within each session, beginning with a CRF component. Each target response was reinforced when the green keylight was illuminated. When the red keylight was illuminated, food delivery was contingent on the demonstrator not emitting any aspects of the target response during variable intervals since the last reinforcer (DRO). The variable intervals were chosen to approximate the rate of reinforcer delivery during the CRF schedule components. A naive pigeon was present in the observer's chamber during the preliminary training of the demonstrator.

The DRO and CRF schedules served two functions. First, they established differentiated demonstrator's behavior as discriminative stimuli for the observer's behavior. Second, delivering food on the DRO at a similar rate to the CRF schedule eliminated the possibility that different rates of demonstrator feeding or magazine operation could serve as an additional discriminative stimulus for the observer's behavior. Pigeons N1 and ND were trained for about 20 sessions, at which time a consistent level of performance was achieved.

Experimental sessions. The observers participated in 14 sessions. Pigeons N2 and N4 performed with Demonstrator N1 and Pigeons N3 and N5 performed with Demonstrator ND. For the demonstrators, in each session three CRF components signaled by the green keylight alternated with three DRO components signaled by the red keylight. For the observers, S+ and S− components were both signaled by a yellow keylight and there were no other exteroceptive stimuli that differentiated the two components other than the demonstrator's behavior. During S+ components, each target response was followed by food (CRF) while in S− components, reinforcement was withheld (Extinction).

RESULTS AND DISCUSSION

Frequencies of target responses were recorded for each component. The time base for calculation of response rates was the duration of the component minus reinforcer duration. Figure 3 shows mean target responses per minute emitted by each observer during S+ components (filled circles) and S− components (filled triangles). Similar data are also presented in Figure 3 for the demonstrators' responses during CRF components (empty circles) and DRO components (empty triangles). The data to the left of the dotted line show rates of target response by the demonstrators during the last three sessions of preliminary training. During the S+ components, target response frequencies by demonstrators appeared stable and were consistent by the final three sessions.

Figure 3 shows that the observers performed at higher rates during S+ components than S− components. Rates of responding by the observers coincided with the demonstrators' response rates during S+ components. The observers performed target responses at a low rate during S− components, in contrast to the demonstrators who emitted none. That is, the observers responded differentially during S+ and S− components when the only available discriminative stimulus was the demonstrator's behavior. Differential reinforcement therefore contributed to the acquisition of matched responding by the observers as their responding was under the control of topographically similar behavior of the demonstrator.

EXPERIMENT 4

In Experiment 3, reinforcers were delivered following each target response in the S+ components and not in the S− components. This produced rapid acquisition of differential responding. However, the discriminative properties of reinforcer occurrence in the observer's chamber were also likely to be high.

● Observer in S +
▲ Observer in S -
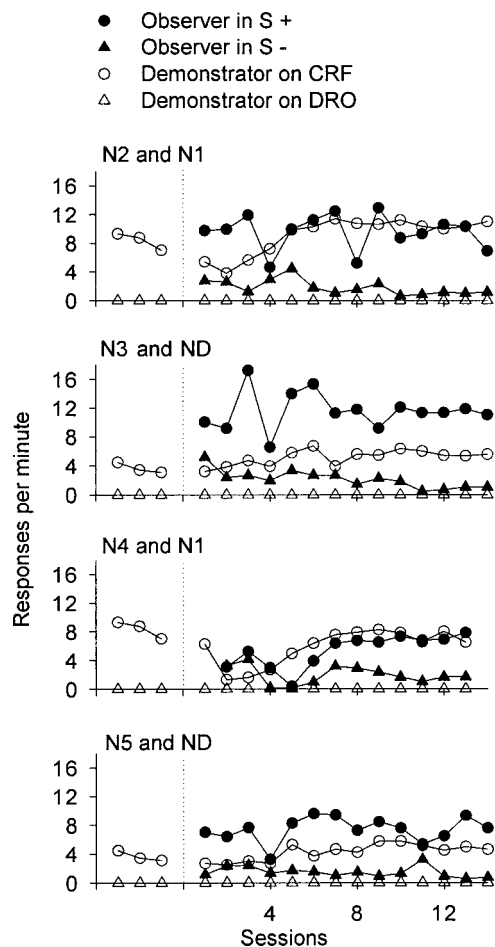○ Demonstrator on CRF
△ Demonstrator on DRO

Fig. 3.   Mean target responses (step on the box and peck 10 times) per minute for observers (filled symbols) and demonstrators (unfilled symbols) in Experiment 3 where the demonstrator's behavior served as the discriminative stimuli for the observer's behavior which was continuously reinforced or in extinction in S+ and S− components, respectively, within sessions. Data for three preliminary training sessions for demonstrators are also shown.

In Experiment 4, the general procedure of Experiment 3 was followed, but the reinforcement schedule in the S+ components was changed to a VI schedule so that fewer reinforcers were provided and the first response in a component was not necessarily reinforced to eliminate or reduce reinforcer occurrence as a potential discriminative stimulus. In addition, a probe test was conducted in extinction to assess discriminative control in the absence of reinforcer occurrence.

METHOD

Subjects and Apparatus

The subjects and apparatus were as in Experiment 1.

Procedure

This was as for Experiment 3 except as noted below. Each observer participated in 23 sessions. In S+ components, reinforcers followed an observer's target response after variable intervals since the last reinforcer, averaging 20 s (VI 20 s). In S− components, reinforcement was withheld (Extinction). During S+ components, the demonstrator's target responses were reinforced on a VI 20-s schedule, whereas during the observer's S− components, demonstrator's behavior other than target responses was reinforced on a DRO schedule at a rate averaging one reinforcer per 20 s. The other main change was that each observer received one probe test for discriminative control by reinforcer occurrence. This was done by not reinforcing target responses that occurred during the second S+ component of Session 14. For Pigeon N2, the probe test was conducted in Sessions 15 and 17.

Other changes from the procedure of Experiment 3 were as follows: (a) there was a random order of the three S+ and three S− components in each session; (b) the target response was modified so that observers and demonstrators were required to peck five times instead of 10—this increased the number of target responses possible in a component; and (c) components were lengthened to 285 s, excluding the time taken to complete the demonstrator's first target response.

RESULTS AND DISCUSSION

Figure 4 shows observers' target responses per minute averaged over the three components in each session for S+ components (filled circles) and S− components (filled triangles). Data are also shown for the demonstrators' responses during S+ components (empty circles) and during S− (DRO for demonstrators) components (empty triangles), for experimental sessions and also for the three preliminary sessions. The demonstrators consistently emitted many target responses during VI 20-s components and no responses during DRO components. These
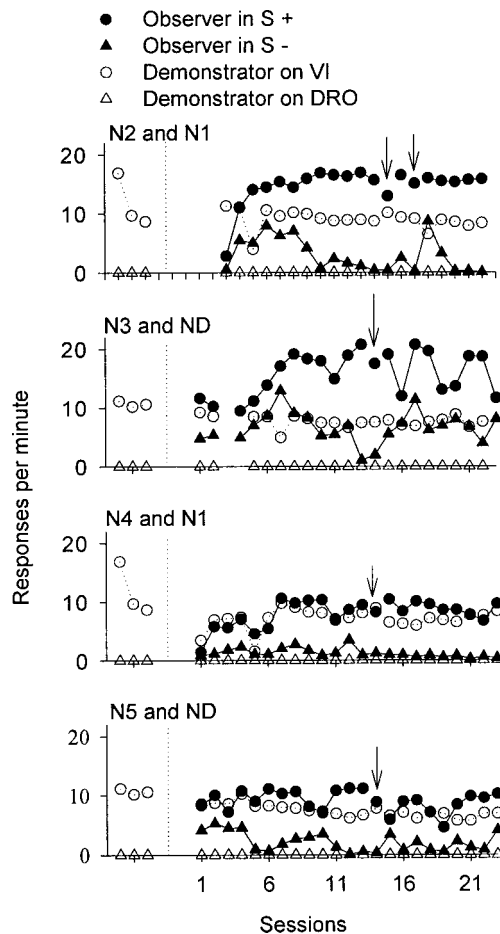
Fig. 4. Mean target responses per minute for observers (filled symbols) and demonstrators (unfilled symbols) in Experiment 4 where the demonstrator's behavior served as the discriminative stimuli for the observer's behavior which was reinforced according to a VI 20-s schedule or in extinction in S+ and S− components, respectively, within sessions. Data for three preliminary training sessions for demonstrators are also shown.

components were S+ and S− components, respectively, for the observers. Each observer responded more frequently during S+ components than during S− components. The results of the probe tests, identified by the arrows in Figure 4 (only for the probed component), indicate that the observers continued to respond in the same way as in other S+ components, and, more importantly, maintained the response differential between S+ and S− components. The results of the probe test show that the observer's behavior was not under stimulus control of reinforcer

occurrence but was determined by the demonstrator's behavior.

In Experiment 4, the observers emitted target responses at a high rate in the presence of the demonstrator performing the same response and at a low rate in the presence of the demonstrator being fed only. This study confirmed the conclusion of Experiment 3 that the behavior of the demonstrator served as a discriminative stimulus for target responding by the observers. Additionally, the probe test showed that reinforcer occurrence did not serve as a discriminative stimulus. The overall finding is that the observers' matched responding was under the discriminative control of the behavior by a conspecific in that they stood on the box and pecked five times at a high rate when the demonstrator was also performing this target response, and at a low rate when the demonstrator was being fed only.

EXPERIMENT 5

In Experiment 5, matched-dependent learning was demonstrated for target responding when it was deferred from the time of the demonstrator's behavior. In Millard's (1979) study, and the present Experiments 3 and 4, the observer's response opportunities were simultaneous with the demonstrator's behavior which served as discriminative stimuli for the observer's behavior. In Experiment 5, the opportunity for occurrence of the observer's behavior was deferred or delayed in time from occurrence of the demonstrator's behavior, thus precluding social facilitation as a possible account for the behavior. Further, by using separate chambers for observer and demonstrator, the possibility of local enhancement was eliminated.

METHOD

Subjects and Apparatus

The subjects and apparatus were as in Experiment 1.

Procedure

The procedure was similar to Experiment 4, with the following exceptions. In Condition 1 (Simultaneous), the observers performed simultaneously with the demonstrator, as in Experiment 4. The observer's 120-s

component did not begin until the demonstrator's first reinforcer was delivered for target responding or DRO responding. Six 120-s periods, three S+ and three S−, were separated by blackouts averaging 60 s.

In Condition 2 (Partially Overlapping), the demonstrator performed alone for 60 s in each component, then both pigeons performed together for 60 s, and finally the observer performed alone for 60 s. Six such 180-s periods, three S+ and three S−, were separated by blackouts averaging 60 s.

In Condition 3 (Deferred), the observer's component did not overlap with the immediately preceding demonstrator's component. Each observer's 120-s component began immediately after the demonstrator's 120-s component. Six such 240-s periods, three S+ and three S− components, were separated by blackouts averaging 60 s. Each observer participated in seven sessions in Condition 1, eight sessions in Condition 2, and eight sessions in Condition 3. During the final session of Condition 3, a probe test was conducted in which the observer's second S+ component continued in extinction. In all conditions, frequencies of the observer's target responses were calculated for consecutive 30-s intervals within each component.

Results and Discussion

Mean target responses per minute in consecutive 30-s intervals over S+ and S− components in each session are shown in Figures 5, 6, and 7 for Conditions 1, 2, and 3, respectively. In Condition 1, the demonstrator's reinforced responding occurred simultaneously with the whole 120 s of the observer's components. Figure 5 shows that each observer's performance did not change systematically over the course of the component for either S+ or S− components. For instance, responding during the 91-s to 120-s intervals showed a similar extent of differential responding to the earlier 0-s to 30-s intervals.

Figure 6 shows that target responses per minute in Condition 2 remained constant across the 30-s intervals in each component. There was little change across the four 30-s intervals, despite the observers performing alone for the final 60 s of the component. In other words, in the last half of their component each observer maintained differential

responding under the delayed discriminative control of the demonstrator's behavior.

In Condition 3, the observer's performance was deferred with regard to the demonstrator's. That is, the demonstrator's behavior immediately preceded the observer's component. Figure 7 shows that target responses occurred at the same rate across consecutive 30-s intervals for both S+ and S− components. These findings indicate the observers responded differentially even when they were not given the opportunity to begin their performance in the presence of demonstrator responding. Furthermore, the observers' response differentials did not noticeably decrease over the course of the 120-s component even though the discriminative stimulus was increasingly removed in time from the behavior it occasioned.

For Pigeons N2 and N3, and for the first 30 s of components for Pigeons N4 and N5, the response differential in the probe test was the same as in the preceding sessions, indicating that the discriminative behavior of the observers was not controlled by reinforcer occurrence. The reduction in rates of target response in the probe test for Pigeons N4 and N5 later in the component suggests some influence of reinforcer occurrence for these pigeons. Rates of target response by the demonstrators (not shown) were consistent across sessions and were differentiated between components.

The present experiment established delayed discriminative control by the behavior of a conspecific over the behavior of an observer. This result has not previously been reported for pigeons. In terms of stimulus control, the result parallels that for delayed control of a simple successive discrimination. White and Redman (1983) arranged a procedure in which two 60-s components of a multiple schedule alternated in succession. Different variable-interval (VI) schedules were in effect throughout each component. The first 15 s of each component was signaled by red and green lights and the remaining 45 s of both components was associated with a white stimulus. The response differential later in the component (in white) was under the delayed control of the color presented earlier. In the same way, the present procedure was a multiple schedule in which the response differential in the deferred condition
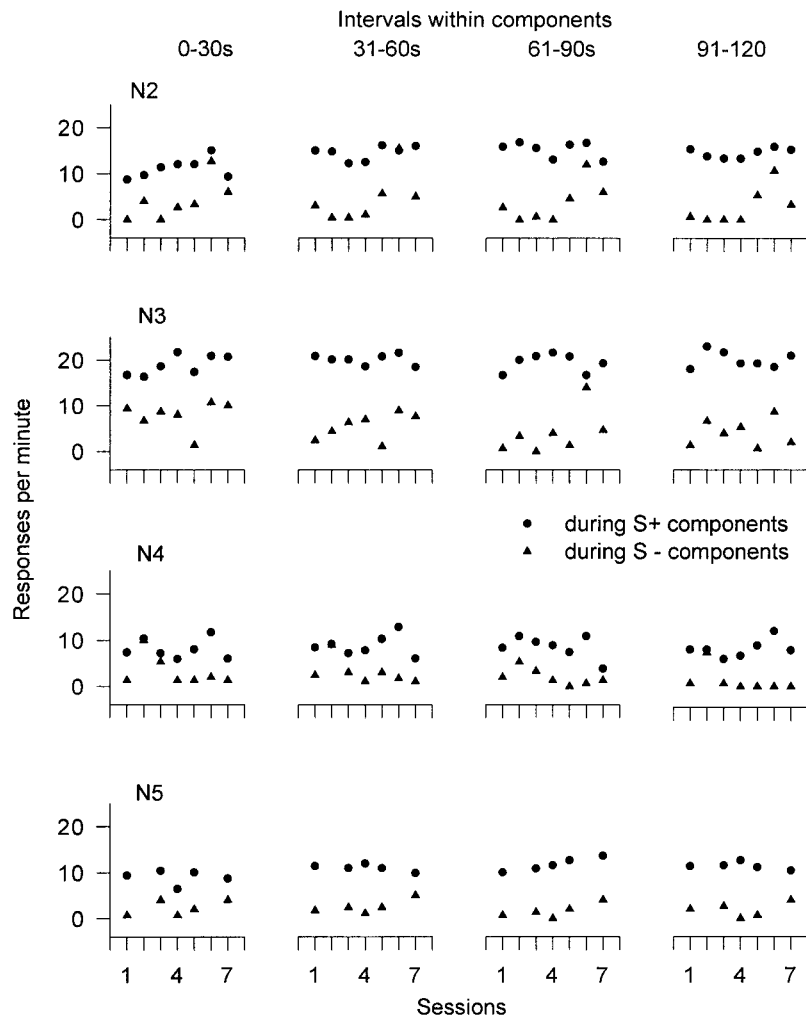
Intervals within components

Fig. 5. Rates of target response in consecutive 30-s intervals of S+ and S− components across session in three conditions in Experiment 5 where the observer's opportunity to respond in the 120-s component was simultaneous with the demonstrator's component.

was under delayed stimulus control of the demonstrator's behavior observed at an earlier time. White and Redman showed that the reinforcement differential was an important factor in maintaining discriminative control. Similarly, the results of Experiment 3 suggest that matched-dependent learning in a procedure where social influence is delayed depends on differential reinforcement of discriminative behavior.

GENERAL DISCUSSION

In the present experiments, local enhancement, where the demonstrator's activity at a

particular location (or stimulus) may draw the observer to that location (Zentall, 1996), was precluded by using separate experimental chambers for demonstrator and observer. Additionally, social facilitation was precluded by delaying the observer's opportunity to respond relative to the demonstrator's behavior. In Experiment 1, there was no evidence for social learning in the absence of reinforcement of the observer's behavior. In Experiment 2, there was no evidence for social influence when the target response was already established in the observer's repertoire but was not differentially reinforced in relation to the demonstrator's behavior. Rein-
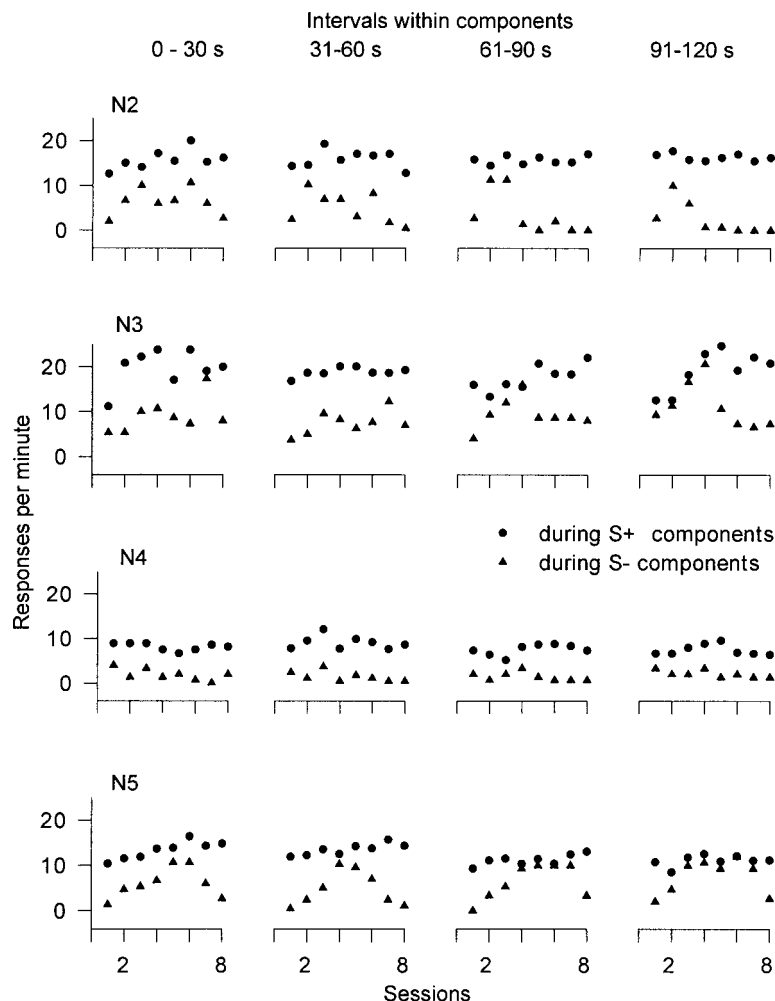
Fig. 6.   Rates of target response in consecutive 30-s intervals of S+ and S− components across sessions in three conditions in Experiment 5 where the first 60 s of the observer's opportunity to respond overlapped with the last 60 s of the demonstrator's component.

forcement only in the presence of the modeled target response, and not in its absence, did result in target responding by the observer in the presence of the modeled target response (Experiments 3 and 4). The observer's responding in Experiments 3 and 4 was consistent with the matched-dependent learning reported by Millard (1979) in the sense that target responses by the observers were not controlled by the occurrence of reinforcement but by the behavior of the demonstrator. This control was extended in Experiment 5 to responses that occurred in the absence of the demonstrator; that is, to behavior under deferred discriminative control.

The acquisition of social learning in Experiments 3, 4, and 5 depended on differential reinforcement of the observer's target response (standing on the box then pecking the key), with the demonstrator's target behavior serving as the explicit discriminative stimulus. It was not sufficient that the observer's target behavior was reinforced in order to establish social learning. Instead, reinforcement had to be signaled by the observer's behavior, consistent with established principles of discriminative stimulus control.

Of the varieties of social learning, imitation has received the greatest attention. Demonstrations of imitation, however, must be sep-
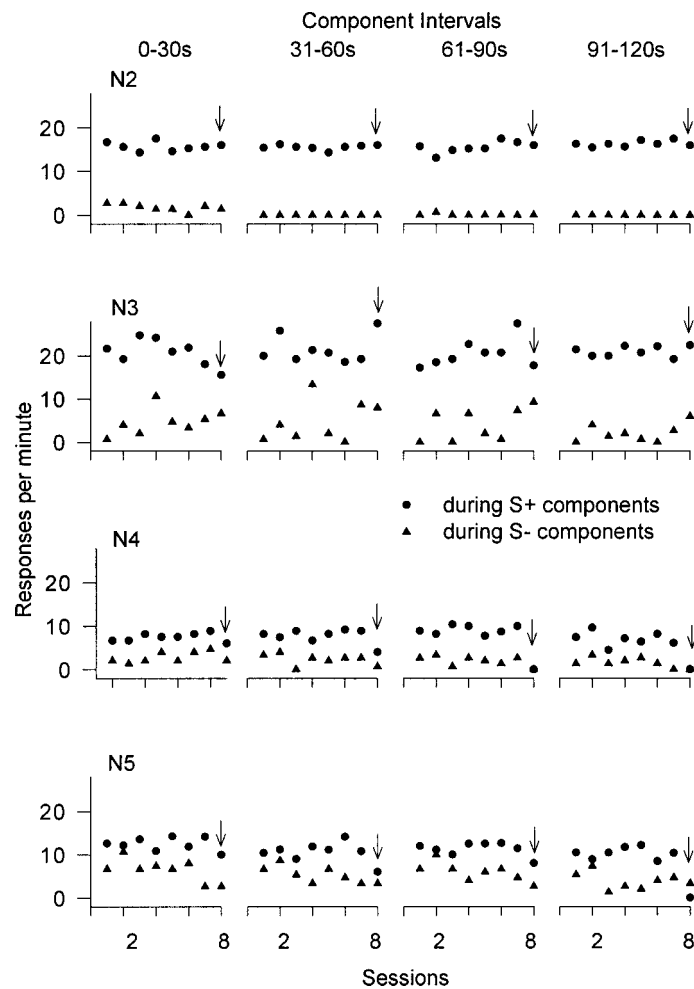
Fig. 7. Rates of target response in consecutive 30-s intervals of S+ and S− components across sessions in three conditions in Experiment 5 where the observer's deferred opportunity to respond in the 120-s component did not overlap but directly followed the demonstrator's 120-s component.

arated from other influences such as social facilitation and local enhancement (Fragaszy & Visalberghi, 1989; Galef, 1988; Heyes, 1996; Howard & Keenan, 1993). According to Zentall (1996), true imitation excludes behavior that is facilitated solely by the presence of the demonstrator and behavior which is part of the organism's phylogenetic repertoire and is elicited by the behavior of a conspecific (social facilitation). Additionally, imitation excludes behavior which occurs because the observer's activities are directed towards a location or operandum associated with food obtained by the demonstrator (local or stimulus enhancement).

Owing to the control procedures used in the present experiment, social facilitation and local enhancement were precluded as potential sources of control of the observer's behavior. The social learning in Experiments 4 and 5 bore some similarity to imitation in that human observers who saw a videotape of the deferred matched responding in Experiment 5 readily identified the observer's behavior as imitating the demonstrator's behavior. This was especially the case for the novel finding in Experiment 5, where the observer's behavior was deferred. But owing to the explicit arrangement of differential reinforcement, the social learning reported in

the present experiment is by convention termed "matched-dependent learning" (Galef, 1998).

In social learning, the demonstrator's behavior serves as a source of discriminative stimulus control, just as hues might in a simple successive discrimination. In other words, social learning is subject to the same stimulus control principles as is other discriminative behavior. Typically, discriminative control depends on differential reinforcement, but imitative behavior is said not to be established through differential reinforcement (Zentall, 1996). Therefore, the behavior in the present Experiment 5 was not truly imitative because its differential occurrence was brought under discriminative control by the demonstrator's behavior through explicit differential reinforcement. Nevertheless, in principle it would be possible to show that it could be generalized to other novel behaviors (Baer, Peterson, & Sherman, 1967; Deguchi, 1984).

The role of differential reinforcement in studies of imitation, however, has not been satisfactorily addressed. Most experiments on imitation in nonhuman animals provide reinforcement contingent on imitative responses. For example, Zentall, Sutton, and Sherburne (1996) recently demonstrated imitation in pigeons. For 15 min, each of 12 pigeons observed a demonstrator stepping on a treadle and 12 pigeons observed a demonstrator pecking the treadle. During the 30-min test, 9 pigeons that observed a demonstrator stepping on the treadle also stepped on the treadle and 3 did not respond. Of the pigeons that watched the demonstrator peck the treadle, 5 pecked it, 5 stepped on it, and 2 did not respond. Similar results were reported for quail by Akins and Zentall (1996, 1998) and by Dorrance and Zentall (2001). As Kaiser, Zentall, and Galef (1997) note, the result reported for pigeons by Zentall et al. could be explained in terms of local enhancement. Kaiser et al., therefore, described the results for two control groups. Three of 12 control pigeons that observed a naive demonstrator stepped on the treadle, and none pecked it, and 2 of the 12 pigeons that observed a naive demonstrator eating stepped on it. These frequencies were lower than the number of pigeons (9 of 12) stepping on the treadle in the study by Zentall et al. Kaiser et al. concluded that imitation was an appropriate in-

terpretation although it applied only to treadle stepping. However, reliable responding to the treadle was defined as a minimum of 50 responses. Because each response was reinforced, reinforcement may have amplified treadle stepping to a greater extent than treadle pecking if it was easier to operate the treadle by stepping than by pecking. That is, pecking may also have occurred but for fewer than 50 responses owing to force-requirement differences. The fewer control group subjects that treadle pressed may have been the result of the use of experienced pigeons by Zentall et al. and naive pigeons by Kaiser et al.

The main difference between the present Experiments 4 and 5 in which social learning was obtained, and recent studies of imitation using the "two-action" method (Akins & Zentall, 1996, 1998; Kaiser et al., 1997; Zentall et al., 1996) was that in the present experiments the observers were explicitly trained to perform a similar response as the demonstrator by differential reinforcement. In contrast, in the studies where imitation has been claimed, the first response in the test may have imitated the behavior of the demonstrator, although the relevant data are not always clear. In some cases the first imitative response may be determined by local enhancement, as appeared to be the case in some studies using the two-action method (Campbell, Heyes, & Goldsmith, 1999; Heyes & Dawson, 1990; Heyes, Dawson & Nodes, 1992; Mitchell, Heyes, Gardner, & Dawson, 1999), or by some other factor such as amplification of responding by reinforcement. In other words, where imitation has been claimed, the contributing factors are unclear although all recent studies have included differential reinforcement.

The potential role of reinforcement in previous demonstrations of imitation is suggested by the results of recent studies with quail. Akins and Zentall (1998) reported imitation only for observers that watched a demonstrator whose behavior was reinforced, compared to demonstrators whose behavior was not visibly reinforced. Dorrance and Zentall (2001) reported imitation in quail only when the observers were food deprived. In those studies, local enhancement combined with amplification of response probability by continuous reinforcemement of the observer's behavior was possible because the observers were trans-

ferred to the demonstrator's chamber where the observers had previously been magazine trained.

Without opportunities for local enhancement or social facilitation and with no differential reinforcement, as in the present Experiment 1, imitation does not occur. With the involvement of differential reinforcement, it is difficult to distinguish true imitation, in terms of the usual criteria (Zentall, 1996), from the matched-dependent learning demonstrated in the present Experiment 5. The best conclusion, therefore, is that imitation is subject to the principles of stimulus control, including differential reinforcement.

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